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Influence of surface tension gradient on liquid circulation time in a draft tube airlift reactor

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ABSTRACT

This paper investigates the impact of surface tension gradient on liquid circulation time in a draft tube airlift reactor using dilute alcohol solutions. The experimental work proves the existence of three bubble regimes (*Regime I*: no bubbles in the downcomer; *Regime II*: a stagnant swarm of bubbles in the downcomer; *Regime III*: circulation of bubbles through the reactor) in the downcomer. A paired sample *t*-test also confirms the presence of these hydrodynamic regimes. The liquid circulation time results can be predicted from a proposed correlation which has two independent variables: surface tension gradient in dilute alcohol solutions as a variable representing the physical property of liquid phase, and superficial gas velocity as a hydrodynamic variable. The statistical evaluation quantifies the influence of each independent variable through its elimination from the proposed correlation. Additionally, the second approach compares the rate of change in the liquid circulation time with respect to the surface tension gradient and the superficial gas velocity. It was found that the superficial gas velocity was more significant variable than the surface tension gradient for all three hydrodynamic regimes. The influence of the surface tension gradient on the liquid circulation time was insignificant at lower superficial gas velocity due to a negligible amount of bubbles in the reactor. However, the opposite was true at higher superficial gas velocity. It is evident that in the draft tube airlift reactor environment, the effect of surface tension gradient on liquid circulation time largely depends on superficial gas velocity.

1. Introduction

Airlift reactors are widely used in fermentation industry and wastewater treatment. In these reactors, the properties of liquid phase may have a profound effect on the bubble size, consequently influencing the hydrodynamic and mass transfer behaviour of the reactor (Albijanic et al., 2007). If surface tension of dilute aqueous solutions of alcohols is the only physical property of liquid phase that exhibits significant difference from water, these solutions can be used to simulate the behaviour of these reactors. The addition of a small amount of alcohols in aqueous solutions strongly suppresses coalescence between bubbles due to the formation of a rigid monolayer around bubbles, making their surfaces immobile (Al-Masry and Dukkan, 1997; Krishna et al., 2000). When a bubble rises through a liquid, adsorbed alcohol molecules move to the back of the bubble, and cause the surface tension gradient that resists the tangential shear stress. Therefore, the increase

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Table 1 – A review of investigations of the liquid circulation time for the dilute alcohol solutions in the draft tube airlift reactors.

Author	D (cm)	D_R/D (%)	Type of sparger	Liquid
Fields and Slater (1983)	15.2	63	Porous plate	1% ethanol
Weiland (1984)	20	59, 74, 88	Sinter plate, $d = 150–200\,\mu m$	Water 0.22% 2-propanol
Petrovic et al. (1991)	20	40, 50, 75	Perforated plate, 19 holes, $d = 1$ mm	Water 0.5% n-butanol
Kennard and Janekeh (1991)	22	45	Sinter plate, $d = 150\,\mu m$	Water 10 g/L ethanol+ 0.5 g/L CMC
Freitas and Teixeira (1998)	14.2	119	Perforated plate, 30 holes, $d = 1$ mm	Water 10 g/L ethanol
Albijanic et al. (2007)	10.6	51	Single orifice, $d = 4$ mm	Water, 1% methanol, ethanol, n-propanol, isopropanol, n-butanol
This work	10.6	51	Single orifice, $d = 4$ mm	Water, 0.5% methanol, ethanol, n-propanol, isopropanol, n-butanol

D_R, diameter of draft tube; D, diameter of column.

in the drag force on the bubble reduces the bubble rise velocity (Krishna et al., 2000), which improves the entrainment of bubbles in the downcomer section of the reactor (Albijanic et al., 2007). The presence of bubbles in the downcomer may have a significant effect on liquid circulation because the driving force for liquid circulation is directly proportional to the difference between the gas holdup in the riser and that in the downcomer (Albijanic et al., 2007; Sijacki et al., 2010).

Liquid circulation not only facilitates mixing of solids, but also it improves heat and mass transfer in airlift reactors, and consequently, the determination of liquid circulation in these reactors becomes very important. In previous studies, the circulation time of dilute alcohol solutions in draft tube airlift reactors has been determined experimentally (Fields and Slater, 1983; Weiland, 1984; Petrovic et al., 1991; Kennard and Janekeh, 1991; Freitas and Teixeira, 1998; Albijanic et al., 2007). However, the impact of physical properties of dilute alcohol solutions on liquid circulation time has not been statistically quantified. Realizing the potential value of this work, in the following sections, we present a review of the relevant previous studies, the methodology that describes both experimental and statistical approaches, a detailed discussion on results implementing both approaches, and conclusions.

2. Previous work

Table 1 presents a concise review of studies on the liquid circulation time for the dilute alcohol solutions in the draft tube airlift reactors. The literature reveals that the factors like geometry and the type of spargers establish whether the addition of alcohols affects the liquid circulation time.

In this context, Chakravarty et al. (1974) reported that the influence of added alcohol on the liquid circulation time was negligible even though the surface tension of liquid phase changed from 0.049 to 0.072 N/m. The reason is that these authors used a short draft tube (0.04 m), causing considerable reduction in the driving force for liquid recirculation. Freitas and Teixeira (1998) also reported similar observations since their reactor had a large separator section which reduced the entrainment of bubbles in the downcomer. On the contrary, Petrovic et al. (1991) and Albijanic et al. (2007) used a long draft tube and observed that the addition of small amount of alcohols increases the liquid circulation time considerably, mainly due to extensive entrainment of bubbles in the downcomer which reduced the driving force for the liquid circulation.

Apart from the geometry of the airlift reactors, the type of the spargers may affect the hydrodynamic behaviour of liquid phase. For example, Weiland (1984) found that the circulation time of dilute alcohol solutions was 50% higher as compared to that in tap water at lower superficial gas velocities. The reason is that the sinter plate resulted in improved entrainment of bubbles in the downcomer. However, at higher superficial gas velocities, the circulation time of dilute alcohol solutions remained 25% lower than that in tap water due to the intense turbulence of the liquid phase.

In the context of the prediction of circulation time of dilute alcohol solutions, Albijanic (2006) used the correlation that accounts for the superficial gas velocity, the surface tension of alcohol solutions, and the number of carbon atoms in the molecule of alcohol. Although this correlation successfully described the experimental data, the surface tension of alcohol solutions and the number of carbon atoms in the molecule of alcohol are not independent variables. Namely, surface tension of dilute solutions of alcohol with a higher number of carbon atoms is lower than that of alcohol with a lower number of carbon atoms. It is important to highlight that surface tension better represents the physical properties of dilute alcohol solutions than the number of carbon atoms in the molecule of alcohols because different isomers of the same molecule of alcohol have the same number of carbon atoms, but dilute solutions of these isomers may have different values of surface tension (e.g. surface tension for 1% propanol is 61.8×10^{-3} N/m, while that for 1% isopropanol is 59.6×10^{-3} N/m (Albijanic et al., 2007)). For that reason, Albijanic et al. (2007) proposed the correlation with two independent variables: superficial gas velocity and surface tension gradient, and their proposed correlation successfully predicted the experimental data.